
BLIND FLYING ON THE BEAM AERONAUTICAL COMMUNICATION, NAVIGATION AND SURVEILLANCE: ITS ORIGINS AND THE POLITICS OF TECHNOLOGY: PART ONE—FORM AND FUNCTION

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ABSTRACT

In this first part of a three-part series, the technological and political progress from the earliest attempts at wireless communication to research on *fog signaling*, *blind flying* and early Post Office attempts at surveillance are examined. During this period, government agencies such as the War Department, Navy, Post Office and the National Bureau of Standards pursued various projects while testing technologies and methodologies for aerial electronic communication and navigation. Their research relied on administrative funding that could be very substantial or non-existent, depending on the national political climate. The second part of the series considers the effect of Federal regulatory and administrative policy on the development of aeronautical communication and navigation in the United States (U.S.). The third part analyzes the effect of the continued Federal oversight during the Great Depression and the progress of aeronautical telecommunications research and the deployment of such technologies in support of aviation.

INTRODUCTION

For more than 33 hours nobody knew where he was or if he was even alive. There were reports that he had been seen over St. Johns, Newfoundland, and a second sighting positioned him some 500 miles from the coast of Ireland. Then at 10:21 p.m. on May 21, 1927, young airmail pilot Charles Lindbergh guided his aeroplane, the Spirit of St Louis, onto the grassy runway of Le Bourget Aerodrome, Paris, France. He had made

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history—the first to successfully negotiate the mercurial weather of the Atlantic Ocean, flying alone, non-stop from the U.S. to Europe (Knight, 1997; State Department, 1927).

Of the many technological challenges facing *Lucky Lindy*,¹ pre-flight weather information and in-flight navigation were critical to the success of his venture. What distinguished Lindbergh's flight was not only that it was the first solo transatlantic crossing in an aeroplane, but that he had completed it without any of the communication and navigation capabilities employed in aircraft of today (Lindberg, 1953).

The Spirit of St Louis's primary navigation instrument was a compass. There were no electronic navigation aids (NAVAIDS) for guidance, and communication technology was still in its infancy and considered unreliable by Lindbergh. He preferred to take on more fuel rather than sacrifice it to the additional weight required by an undependable radio (Lindbergh, 1953).

His greatest challenge, navigation over open water, had to be accomplished by computing flight time, the effects of wind velocity and direction, and correcting for compass error. The exact location of the aircraft was, at best, an approximation (Komons, 1978; Snyder & Bragnaw, 1986). Even though direction-finding concepts and technologies for aircraft were being developed and refined by the National Bureau of Standards, the Army and the Navy, they were not yet placed in general use (Lindbergh, 1953).

Navigation was not the only obstacle with which Lindbergh had to contend. He faced the challenge of unforeseen weather as well—not knowing what weather he would encounter enroute or upon his landing in France. Without a radio, it was impossible for anyone on the ground to communicate the changing weather patterns he might encounter. Such unforeseen weather did, in fact, force him to deviate from his planned flight during the night, leaving him unsure of his position by morning. As he continued his flight eastward, he sighted land, flew towards it and happily discovered he was over Ireland.

A fjorded coast stands out as I approach.... Yes, there's a place on the chart where it all fits—line of ink on line of shore—Valentia and Dingle Bay, on the southwestern coast of Ireland!

I can hardly believe it's true. I'm almost exactly on my route, closer than I had hoped to come in my wildest dreams.... What happened to all those detours of the night around the thunderheads? Where has the swinging compass error gone? (Lindberg, 1953, p. 463)

Lindbergh was back on course and less than five hours from Paris.

His experience in navigating from New York to Paris was not unlike what he had encountered flying the mail in the U.S. At home, navigation

technology consisted of a series of lights spaced ten miles apart connecting important cities. They worked well when there was no weather or fog obscuring their view but were of little value when the pilot encountered obstructions to visibility (Komons, 1978). If aircraft were to be dependent on the whims of changing weather patterns while lacking the capability to communicate with each other or those on the ground, commercial aviation would never be able to develop as a viable transportation mode. If air transportation operations were limited to pilotage, navigating when the weather allowed identification of landmarks, or dead reckoning, calculating aircraft position by time in the air and heading, then the precise navigation required to support high-altitude, all weather flight would be impossible. Aviation radio expert Henry Roberts commented, “That is why *radio navigation* is the mainstay of modern air transportation” (1945, p. 3).

As early as 1920, the impact electronic navigation and communication would have on aviation was clearly understood. The Manufacturers Aircraft Association, commenting in the *Aircraft Year Book, 1921*, pointed out that the result of such aids “will be that aircraft will be navigated with a safety and dependability far exceeding that now obtained on steamships” (p. 87). What began as an experiment with airborne telegraphy in the early part of the twentieth century has evolved into a sophisticated aeronautical communication system that not only employs, but is dependant upon aeronautical telecommunications technologies. As aviation historian William Leary (1995) points out, the utility of the airplane is dependent upon such technologies.

AERONAUTICAL TELECOMMUNICATIONS

Aeronautical telecommunications are systems employed for the purpose of transmitting navigational information, voice communication, and aeronautical data, including aircraft surveillance, via telephony, telegraphy, radio or cable in support of two-way air-to-ground, air-to-air and ground-to-ground (point-to-point) communication. These technologies define the three constituent elements of aeronautical telecommunications: communication, navigation and surveillance (CNS).²

As used in this paper, aeronautical telecommunications is electronic two-way, air-to-ground and point-to-point transmissions, while navigation encompasses electronic aids enabling flight between defined points. Both communication and navigation make possible the third element of aeronautical telecommunications—surveillance. Surveillance communicates the aircraft’s position both on the ground and in flight and end users of such information may include air traffic controllers, pilots, company managers and dispatchers. The acronym CNS was introduced to clarify the

roles and function of technologies that make possible Air Traffic Management (ATM). ICAO's CNS rubric will be used in this and the following papers to help frame the early development and evolution of aeronautical telecommunications (ICAO, 1994).

Experimentation with aeronautical telecommunications in heavier-than-air aircraft began in 1910, only seven years after the Wright brothers' first powered flight (Roberts, 1945). As the aeronautical telecommunications system began to form, electronic airways would emerge; air-to-ground and point-to-point communication systems would be created, and wire-based telephonic and telegraphic circuits supporting weather reports, flight data (an early form of surveillance) and administrative messages would evolve.

Radio aids to navigation and communication technologies enabled aircraft to fly at any time and in almost any type of weather. They provided the key elements that permitted scheduled flight with regularity and safety (Leary, 1995). The early development of aeronautical telecommunications is based on the work of a small group of government officials and bureaucrats, physicists, scientists, and test pilots. Their tenacity and creativity built a navigation and communication system that was emulated by other nations and provided the essential infrastructure that made possible the realization of the commercial aviation industry in the U.S. (Leary, 1995).

One government official, Herbert Hoover, the Secretary of Commerce during the Harding and Coolidge administrations, and later President, was in a position to wield great influence on the development of the aeronautical telecommunications system. As Secretary, Hoover oversaw the operations of the National Bureau of Standards (NBS). This organization assisted the Navy and War Department in the development of aeronautical radio in World War I, and beginning in 1918, assisted the Post Office in solving aircraft navigation problems. Hoover also supervised the operations of the Bureau of Navigation, the only governmental organization prior to 1927, charged with developing regulations for radio broadcasting. The Department of Commerce was responsible for assigning radio frequencies, keys to protecting aeronautical telecommunications broadcasts. In 1926, Hoover was given another mandate. The Department of Commerce was charged with the administrative oversight of aviation, and a new bureaucratic structure was added: the Aeronautics Branch. Hoover directly supervised it as well as the other organizations affecting the development of the aeronautical telecommunications system.

RESEARCH QUESTIONS

This series has two goals. The first examines the role federal administrative policy played in the development of the aeronautical telecommunications system. From the beginning, the government sponsored not only the development, but also the employment of technologies to further military and commercial aviation progress in the U.S. What, then, was the effect administrative policy had on the development of the aeronautical telecommunications system?

The second is to chronicle the development of technologies that became not only the foundation of commercial aviation in the U.S., but the schema upon which modern CNS technologies are based. What technologies were developed and how were they employed to form the aeronautical telecommunications system?

The two questions are interrelated. The relationship between the scientists of the NBS and regulators, those within the Aeronautics Branch as well as Hoover, would affect the design and deployment of the aeronautical telecommunications system and thereby affect the aviation industry. William P. MacCracken, an aviator, expert aviation law attorney, and the first Assistant Secretary of Commerce for Aeronautics, observed the existence of such a relationship and its importance in a speech in 1928 (Osborn & Riggs, 1970). He pointed out that when coordination between the agencies, the scientists and the regulators was disrupted, it had a profound effect on the aviation industry.

In order to achieve success in the application of aviation to civilian activities...it is necessary to have the closest possible co-operation between those two important agencies. Their problems and methods of dealing with them must of necessity be quite different, though their mutual aim is to increase the scope of air transport service. (Science, 1929)

Overall responsibility for coordination and cooperation between the regulators in the Aeronautics Branch and the scientists at the NBS rested in the Secretary's office. Hoover's policies and political agenda could either encourage or discourage the development of aeronautical communication and navigation technologies and thereby affect the growth of commercial aviation in the U.S.

Prior Research

The origin and evolution of the aeronautical telecommunications system and the interrelationship between scientists, researchers, politicians and bureaucrats who built the system has not been widely researched. Various aspects of the system have been discussed in other works. For instance, development of telephony and radio work conducted by the NBS is

documented in Cochrane's (1976) *Measures For Progress* and Snyder and Bragaw's (1986) *Achievement in Radio*. Aviation telecommunications development is but one of many activities undertaken by the NBS and an in-depth study of aeronautical telecommunications development and its application to aviation is not the focus of either Cochrane or Snyder and Bragaw.

Likewise books such as *Bonfires to Beacons* (Komones, 1978) and *Aerial Pioneers* (Leary, 1985) chronicle the historical and political development of the Aerial Mail Service and the Aeronautics Branch but devote little attention to the technical development of the aeronautical communication and navigation system.

Aviation historian William Leary (1995) offers insight into the technological advances made by the Post Office Department and research conducted by the NBS in the development of the Instrument Landing System (ILS) in his article "Safety in The Air," appearing in *Airships to Airbus*. His investigation of the origins of the ILS, a component of the larger aeronautical telecommunications system, are detailed but other communication and navigation technologies that make up the larger telecommunications system are not considered in his work.

WIRELESS TECHNOLOGY

When Herbert Hoover entered the Department of Commerce in 1921, wireless communication was experiencing a significant paradigmatic shift that would define the form and function of technologies to be used in aeronautical telecommunications. The spark transmitter that had dominated the wireless world was giving way to a new technology—transmitters that could produce continuous waves. These transmitters made radiotelephony possible. Such changes also brought with them new expressions such as *radio* instead of *wireless*. The term broadcasting which had been defined in terms of cable and landline telegraphy was beginning to include present-day concepts.

Wireless broadcasting in the early decades of the Twentieth century was based on Guglielmo Marconi's technique of wireless telegraphy. His system was built around the spark transmitter, an instrument that could create radio waves by producing a series of sparks between a gap built in the transmission circuit. The transmission of Morse code was achieved by controlling these sparks (Aitken, 1985).

Marconi began experimenting with wireless telegraphy in 1895. He understood the benefits and utility of wireless telegraphy especially for marine communication by successfully demonstrating its potential in England. He later formed the Wireless Telegraphy and Signal Company.

Marconi's first customer was the British Government who paid his company £3,200 for an initial order of six land-based and twenty-six transmitting and receiving sets for use onboard ships, making Marconi its sole supplier in 1903 (Headrick, 1991).

Marconi continued improving his system, but even with improvements, this form of radio transmission had its limitations. The spark transmitter was incapable of generating a true continuous sine wave. The reason was simple. As each spark discharged, it created a wave of energy that quickly dissipated in amplitude. The effect is best illustrated by listening to a bell being rung. As soon as the bell is struck, the vibrations in the bell begin to diminish, and more so if the bell is dampened. An electronic dampening phenomenon was inherent, to a varying degree, in all spark transmitters, and the wave produced by a spark transmitter formed a train of damped oscillations containing numerous oscillations within each oscillation. These individual oscillations created a number of constituent frequencies and wavelengths (see Figure 1).

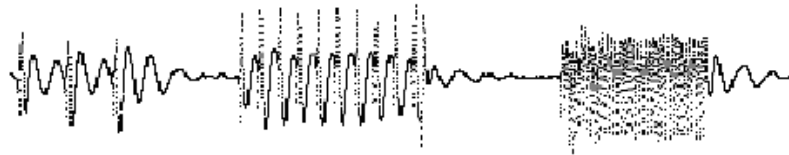


Figure 1. Damped Oscillations from a Spark Transmitter

From *The continuous wave: Technology and American radio, 1990-1932* by H.G.J. Aitken, 1985, p. 5. Copyright Princeton University Press, 1985. Reprinted with permission.

The resulting transmissions created frequency pollution since components of individual sine waves, produced by each oscillation, could be received throughout the frequency spectrum. Since the frequency spectrum is finite, transmissions would only serve to create interference among competing broadcasts. But most experimenters at the turn of the century sought only to improve the spark transmitter. They worked within a technological paradigm that had been proven, and one, which they believed, they could improve (Headrick, 1991). Not all saw it that way. There were a few who understood the limitations of spark technology—its inability to reproduce voice, music or broadcast within a narrower bandwidth. Some of the early experimenters recognized a different approach was required (Headrick).

Continuous sine waves (see Figure 2) were believed to be the solution, but how to generate them was another issue. Radio historian Hugh Aitken

(1985) pointed out that such a transmitter, one capable of generating radio frequencies with the required power, did not exist in 1900. "In the circumstances to believe that continuous wave radio could and should replace spark called for an act of faith" (p. 7).

One believer and experimenter was Reginald A. Fessenden who had begun experimenting with voice transmissions using spark technology in 1900. Unhappy with the results, he sought a way to produce a continuous wave transmission that could be modulated. In 1901, his work resulted in the first wireless telephony patents. He had also invented a way of receiving continuous wave transmissions and named it the heterodyne method. The receiver mixed the incoming radio frequency with a different, internally generated frequency, thereby producing a third, audible, frequency. His methodology initially made no impression in a world of spark transmitters, but would grow in importance as radio technology and the radio industry developed (Snyder & Bragnaw, 1986). It was his methodology that would become the standard for all future radio receivers.

By 1906, Fessenden had successfully demonstrated the feasibility and utility of continuous wave broadcasting. He had done so by using a specially designed alternator built by General Electric. The alternator produced 500 watts at a frequency between 50 and 60 kHz. The technique worked, but it would be years before greater power output and higher frequencies could be attained. Fessenden's alternators were not the only technique for generating continuous waves. A variation of the spark technology, the arc transmitter, had come close to producing the desired sine wave. The Danish scientist Valdemar Poulsen had perfected a transmitter that could utilize an arc as an oscillator (Aitken, 1985).

The most profound breakthrough in wireless technology, however, was the vacuum tube. Lee de Forest is credited with its introduction. Lee de Forest had added a third element in a two-element thermionic vacuum tube,

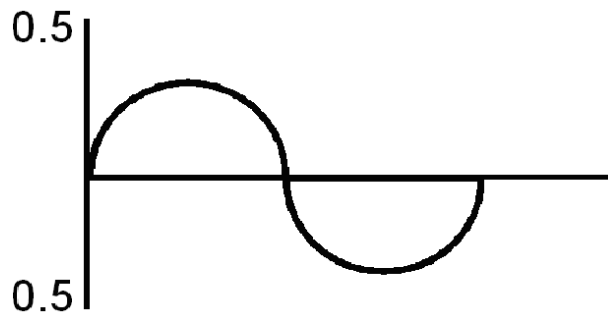


Figure 2. Continuous Wave Transmission

or *fleming* valve.³ His device, known as an *audion*, enabled him to achieve greater receiver sensitivity, and it shortly became the key to producing continuous wave transmissions (Headrick, 1991; Snyder & Bragraw, 1986).

EARLY UNITED STATES TELECOMMUNICATIONS POLICY

European nations such as Germany had worked more closely with their inventors and industry to advance the art of radio. In the U.S., the Navy was competing with the Army's Signal Corps, the Weather Bureau and, ultimately, the private sector. By 1904 President Theodore Roosevelt, weary of the infighting, appointed an Interdepartmental Board of Wireless Telegraphy. But it would be another ten years before the U.S. could achieve a technological level equal to that of Britain or Germany (Headrick, 1991).

As radio became increasingly important to the U. S. armed forces, the NBS, in 1908, offered both the Army and Navy space for radio research. The relationship between the services and the scientists in the NBS's Radio Laboratory allowed close cooperation and an exchange of ideas and information in the areas of radio communication. Although the NBS became a clearinghouse for radio research, it did not have the political stature required to set the agenda. Each service had its own funding and parochial interests. The synergistic relationship between these administrative bodies was clearly helpful, but without a clear national agenda, each military service's narrow interests would always compete with a greater goal.

The Military

The military was the first to attempt to utilize radio communication in aircraft. Experimenting with wireless telegraphy in November of 1912, a young Army aviator Henry H. Arnold and radio operator Second Lieutenant Follet Bradley successfully transmitted the first air-to-ground messages from an airplane (Roberts, 1945).

During World War I, the NBS became the focal point for radio research. The NBS noted the nation was lagging in the application of radio communication in strategic and tactical warfare. In just a few short years, in close association with the military, the NBS Radio Laboratory made progress in the development and application of radio technologies. The NBS reported, "the absolute necessity of radio in modern warfare is apparent" (War, 1920). Problems requiring telecommunications solutions had to be solved quickly, including transoceanic communications, locating enemy units, development of radiotelephony and training the military in their use. The NBS and military would work together to solve these

problems and in so doing would greatly advance the art and technology of radio (War).

Radio Laboratory projects during WWI included research and application of vacuum tube technology and coil antennas as well as work on radio interference and shielding. The Laboratory also produced an important work on radio communication adopted by the Army, Navy and numerous colleges as a radio textbook (Fishbein, 1995).

The most important work surrounded the use of the vacuum tube. In 1917, a scientific mission from France brought with it a number of experiments and radio applications using vacuum tube technologies. The Radio Laboratory report, “the use of electron tubes was practically unknown in the military forces of the U.S. prior to 1917” (Fishbein, 1995, p. 3). The vacuum tube made possible transmitters that could broadcast at higher frequencies than those built around older damped-wave (spark) technologies. Receivers built using the vacuum tubes were much more sensitive and made possible signal amplification. Vacuum tubes also made possible continuous wave transmissions that could be used to carry multiple signals on a single pair of wires thereby increasing the efficiency of landlines. So significant was the impact that the American military required 25,000 tubes weekly. The Radio Laboratory pointed out, “Not much needs to be said to convince the reader that these important applications justify the most extensive and profound research, development, and application” (Fishbein, 1995, p. 3). Vacuum tube technology made possible the efficient amplification of radio signals and would have a significant impact in the world of aviation. Such technology meant aeronautical radios and antennas could now be smaller and lighter—important considerations for aircraft (Cochrane, 1976; Snyder & Bragaw, 1986; Some war-time, n.d.).

During the summer of 1917, the Army, Bell Telephone Laboratories and Western Electric Company successfully demonstrated aeronautical radiotelephony. Western Electric reported that “for the first time in history, airplanes in flight were directed...from the ground...and reports and directions were given and received in clear speech” (Some war-time, n.d.). The tremendous technological strides made were due, in large measure, to the installation of the vacuum tube in radios and related research conducted by the NBS and military services (Snyder & Bragaw, 1986).

NBS involvement in aeronautical telecommunications was just beginning. Even before the end of the war, Post Office officials expressed an interest in radio devices that would enable a pilot to perform a blind landing. Their work for the Air Mail Service and the Army laid the cornerstone for form and function of the future aeronautical telecommunications system (Snyder & Bragaw, 1986).

The Post Office

In July 1918, the Post Office approached the NBS for assistance in developing a type of aeronautical navigation device that would aid a pilot in locating the airfield in conditions of fog or weather. The planning meeting was attended by Otto Praeger, Second Assistant Postmaster, Captain Benjamin Lipsner, Head of the Air Mail Service, and NBS Physicist Fredrick Kolster (see Figure 3). Even though the Post Office had not yet

July 1918

Request made by Postoffice Department for research work on direction finding for use on airplanes of aerial mail service.

Conference during last week of July between Capt. Lipsner
2^d Asst. Postmaster
Mr. Praeger
Mr. Kolster
regarding experimental work to be taken up at College Park about August 15.

Conf. J.A.K. & Dr. Grover re: possibility of using magnetic induction signalling. Calculations show some promise.

Trials of 2-coil apparatus July 29-Aug 3

Figure 3. Notes from the Airplane Radio Journal of Laurens E. Whittemore

From "Airplane Radio Journal of Laurens E. Whittemore." Notes from August 12-17, 1918, p. 1. Dillinger, Files, RG 167, Box 26. National Institute of Standards and Technology, National Archives, Suitland, MD.

begun night flying, it still had to contend with daytime weather conditions. A landing system was required to guide an airmail plane to its destination and allow the pilot to let down through the weather and land safely. Kolster lost no time in beginning his search for an acceptable aeronautical navigation aid. He began working on a system that marked the field for the pilot (Leary, 1985).

Localized Signaling System for Airplane Landing

What Kolster envisioned as a localized landing system, later came to be known as a marker beacon. It was a simple concept. As the pilot approached the field a radio signal marked the landing area. The flight procedure required the pilot to maneuver the airplane so the signal remained in the headset. The signal, broadcast from an antenna buried in the ground, circumscribed the airfield or landing area. The resultant signal could be heard only when the aircraft was over the landing area and would fade rapidly as the aircraft flew away from it. Kolster's design required the pilot to maneuver the airplane so the signal remained in the headsets while the pilot made an instrument decent to the airfield (Airplane, 1918; Localized Signaling, 1920).

Kolster conferred with a colleague, Dr. Fredrick Grover, choosing a signaling system based on principles of magnetic induction offered the best solution. Theoretically, an alternator energizing an antenna at 500 Hz would produce a localized signal that could be received by an airplane in close proximity to it. Kolster began experiments by constructing a 25-foot loop using several turns of wire and powered with a 500 Hz alternator. He was able to induce a signal in a receiver several hundred yards away believing that it would be "practical for one mile signalling [sic] with sufficient power at [the] transmitter" (Cochrane, 1976, p. 196; Airplane, 1918, pp. 6-7). Numerous modifications and trials continued through November when an actual flight test was planned. The simulated airfield was the roof of the newly constructed NBS Radio Building. Kolster coiled six turns of copper wire around its roof and energized it with the alternator. The aircraft, a JN-4 (Jenny) borrowed from the Post Office, had attached to its wing a loop antenna tuned to resonate at 500 Hz. The pilot listened for the signal, amplified by a three-stage amplifier, through a headset. The test flight flown on Armistice Day, November 11, 1918, proved successful. The signal marked the simulated airfield up to an altitude of 3,000 feet (Cochrane, 1976; Airplane, 1918).

In January, work on the signaling device was moved to the airfield in College Park, Maryland, for further experiments. Both the Navy and War department had watched the experiments with interest. Further tests using various configurations based on induction were not as successful and the

project members began experimenting with higher (radio) frequencies. In May, J. A. Willoughby, a member of the team, suggested a system employing two antennas energized in opposite directions (see Figure 4). The configuration produced a signal analogous to an inverted cone with the maximum signal at 30 degrees from vertical. But unexpectedly the localized landing system went into early oblivion (Snyder & Bragaw, 1986). The localized landing system was shelved, and work on a direction finder took precedence. In a January 1921 report, the Radio Laboratory

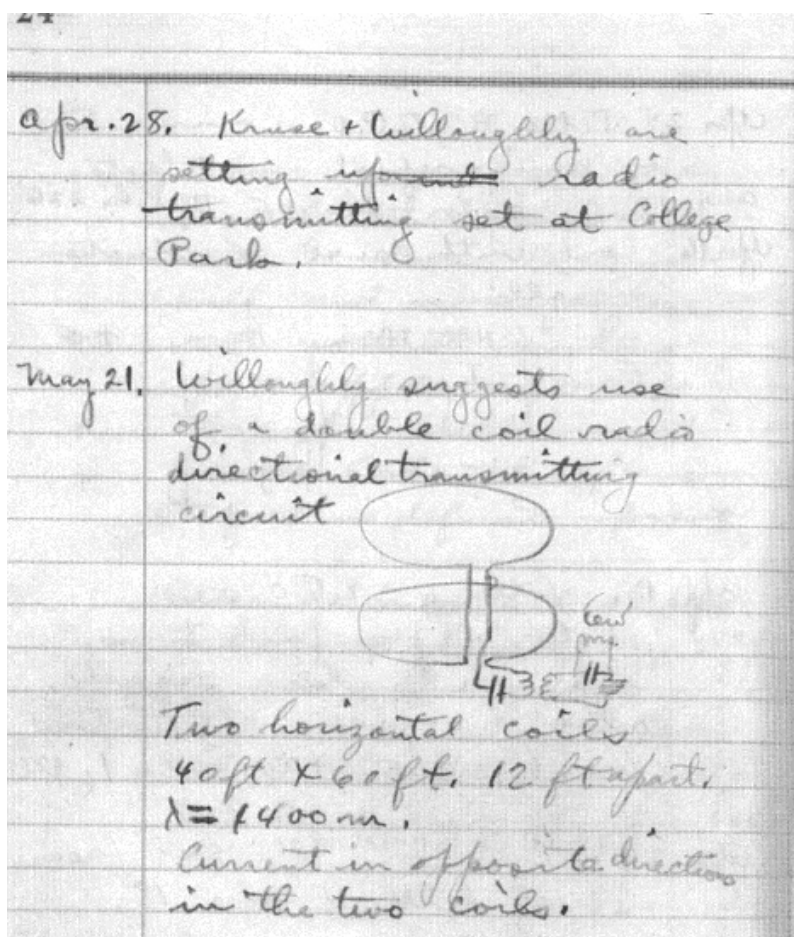


Figure 4. Notes from the Airplane Radio Journal of Laurens E. Whittemore

From "Airplane Radio Journal of Laurens E. Whittemore." Notes from August 12-17, 1918, p. 12. Dillinger Files, RG 167, Box 26. National Institute of Standards and Technology, National Archives, Suitland, MD.

expressed believe that the landing signal system could be improved, but that “it seems advisable to concentrate upon the direction finder work for the present” (Radio laboratory, 1921). The Post Office was very much interested in a direction finding system and funding was found for its development.

The Direction Finder—Historical Development

Wireless direction finding was the original term describing one of two techniques for determining an aircraft’s or a ship’s position. The first is an active system that requires radio operators on the ground to either calculate the airplane’s location and pass the information back to the aircrew or transmit the bearings to the airplane and let the crew do the calculations. The second technique is passive. The crew determines its position by receiving signals broadcast from navigational aids. The U.S. and Europe experimented with both systems during WWI, with Europe adopting the active direction finding methodology and the U.S. ultimately choosing the passive.

Wireless direction-finding experiments began with Marconi in 1900. A year later, Lee de Forest had applied for an antenna patent that facilitated direction finding. These early experimenters discovered if an antenna, built in the shape of an L, was inverted, the longer, horizontal portion was more sensitive to signals being radiated in the opposite direction. In 1905, Marconi patented a direction-finding system built on this concept. But a more practical approach, and one upon which aeronautical navigation in the U.S. would be built, was developed in 1906 by two Italian radio pioneers, Ettore Bellini and Alessandro Tosi. By 1907 the Bellini-Tosi (BT) antenna had become widely accepted for use in both transmitting and receiving and their system would soon form the basis for electronic navigation in the U.S. The BT antenna will be discussed later in greater detail (Fishbein, 1995; Keen, 1927; 1938; Snyder & Bragaw, 1986).

German Navy Zeppelins, using a Telefunken Compass, were one of the first to apply direction finding in aerial navigation. The approach was passive and made use of a rotating beacon. The ground station employed a single antenna supporting thirty-two antennas radiating from the center. An omni-directional start signal was transmitted from the center antenna followed by a signal from each of the antennas at one-second intervals. The signal began and ended at true north. The radio operator on board the airship heard the start signal and began timing with a stopwatch. When the signal was at its greatest volume in the headset, the watch was stopped. The stopwatch had the degrees of the compass on its face and the point where it was stopped represented the bearing from the station. Tuning to another station and following the same procedure, the operator could triangulate the

airship's position (see Figure 5; Keen, 1938; Report No. 6, 1925).

In the U.S., Kolster began direction finding experiments in 1916 by placing a transmitter near the Navesink light station at Atlantic Highlands, New Jersey. Installing a loop antenna aboard the lighthouse tender *Tulip*, he found that the ship could determine the relative bearing to the transmitter. His technique showed promise, but further experimentation and application of Kolster's procedure would have to wait until after the war (Report No. 6, 1925; Snyder & Bragaw, 1986).

The Navy initially approached the problem of direction finding by employing active techniques. They built a series of direction-finder stations on the Atlantic Coast. A vessel would transmit a request that a bearing be taken by land-based stations. Two or more stations would relay the bearings to the ship, enabling the crew to calculate the ship's position. Unfortunately there were serious drawbacks with this approach. First, each land-based transmitter required 24-hour manning by trained personnel. Second, it was

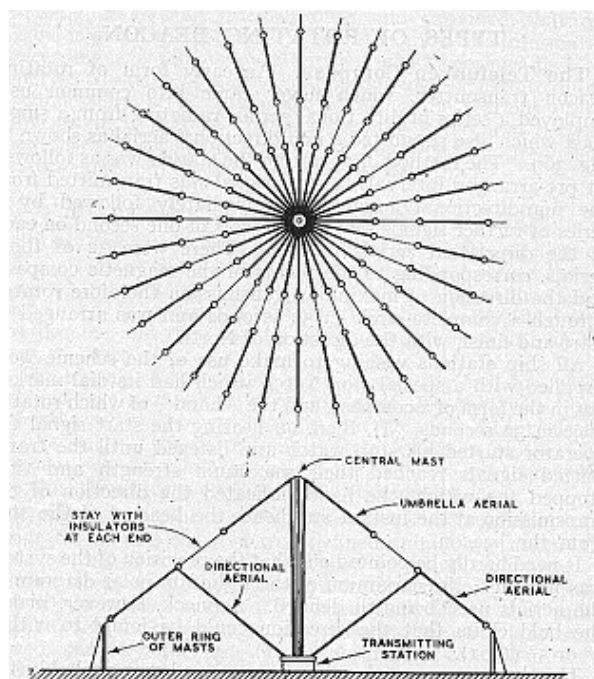


Figure 5. Notes from the Airplane Radio Journal of Laurens E. Whittemore

From "Airplane Radio Journal of Laurens E. Whittemore." Notes from August 12-17, 1918, pp. 6-7. Dillinger Files, RG 167, Box 26. National Institute of Standards and Technology, National Archives, Suitland, MD.

a slow process. Only one ship could be accommodated at a time. The third disadvantage, and most damning for the military, was the fact that while the friendly stations were taking bearings, so was the enemy. Kolster recognized these shortcomings early on and opted for a passive system, one that would allow the calculation of position to be done on-board the vessel without the need to transmit from the ship. In contrast, European nations adopted the active system for aircraft (see Figure 6). Aircraft in flight would transmit and wait for two or three ground stations to telephone bearing information to a master station. The master station calculated the aircraft's position and transmitted the information back to the airplane. The U.S. chose Kolster's methodology (Memorandum in the use, 1926; Report No. 6, 1925; Snyder & Bragaw, 1986).

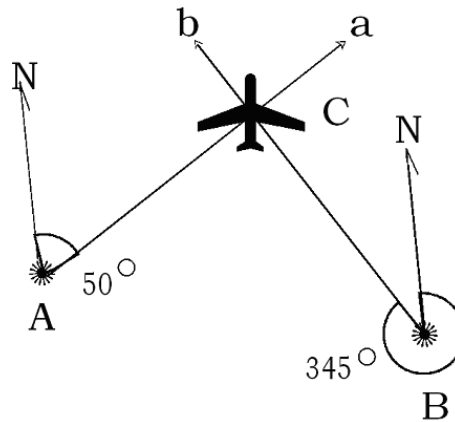


Figure 6. Active Direction Finding

Note: Stations A and B plot bearings (lines a and b) to an airplane that has transmitted a position request. The position (C) is calculated by one of the stations and relayed back to the pilot.

The first radio direction finder built by the NBS was simply a few turns of wire around a small four feet by four feet frame that could be rotated and connected to a receiver. If the antenna were rotated to a position in line with the incoming electrical wave, it would produce the strongest electrical action in the coil. The point at which the antenna was not excited by the signal would occur when the antenna was rotated to a position that was perpendicular to the incoming wave. Thus, the radio direction finder was able to determine the absolute direction of the transmitted wave and boasted accuracy within one degree. But, the device indicated two possible directions of the transmission. Either direction could be located along the line of the transmitted wave. The antenna could not differentiate between a signal originating directly behind of it from a signal originating directly in

front of it. The effect, called ambiguity, was a problem that would eventually be solved by the radio compass, an important component in the aeronautical communication and navigation system (Memorandum on the use, 1926)

By war's end, conferees representing the NBS, Navy and Bureau of Lighthouses reached a consensus to develop a direction finding system based on Kolster's methodology. The advantages of Kolster's system were obvious. A shore station could broadcast continuously with little on-site supervision required. The station would not require 24-hour staffing as did Navy stations, and broadcasts from vessels would not be required to determine, or give away, a position. Continuous improvements in the technology gave birth to a remarkable and extremely satisfactory navigation system for ships. Kolster's radio direction finder, or fog signaling, was of interest to other nations. Responding to a request from the Second Secretary of the Japanese Embassy, Hisoru Fujii, Kolster described the operation and supplied sketches and photographs of the system and offered further assistance (Kolster to Fujii, 1918; Snyder & Bragaw, 1986).

Aeronautical Applications of Kolster's Direction Finding System

In the U.S. direction finding evolved to mean flying towards a beacon or *homing*. The European system was called ground-based direction finding and this technique did find use in the U.S. as an emergency aid for lost pilots. In order to home, pilots, using radio receivers and headsets, turn their aircraft until the signal disappears. At this point the antenna is perpendicular to the transmission and is at the null or minimum signal point (see Figure 7). As previously mentioned, ambiguity is problematic. A single-coil antenna such as the one Kolster employed offers two solutions as does any single-loop antenna. For instance, if the signal is strongest at a ninety-degree angle to the aircraft, the pilot does not know whether to turn right ninety degrees or left ninety degrees. Either choice will produce the same result as far as the antenna is concerned (Kolster to Fujii, 1918; Snyder & Bragaw, 1986).

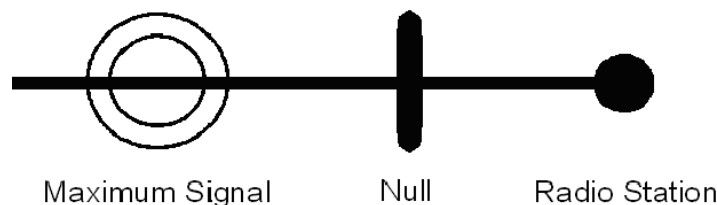


Figure 7. Maximum and Null Antenna Positions

Early Post Office test flights using direction finding were done in a borrowed Navy Curtiss R4L biplane. Two coils, A and B, were attached to the airplane and wired to an amplifier. The A coil was wound around the airplane's landing gear strut parallel to the longitudinal axis of the aircraft while the B coil was wound at a 90 degree angle. The pilot was able to switch between each coil. The A coil, providing the strongest signal, was used to locate the signal source and fly towards it. Once the airplane was in close proximity to the beacon, the B coil was used for more precise navigation. The B coil produced a null or minimum signal strength when the aircraft was pointing directly at the station since it was perpendicular to the incoming electrical wave.

A series of flight tests in the summer of 1920 produced mixed results. The Post Office used radio stations at College Park, Philadelphia and Newark to test the direction finding system. Signals were broadcast from the three stations in five-minute intervals to avoid interference. Aerial Mail pilot Wesley Smith described one successful flight on May 20 stating he relied solely on the radio compass to locate the station at Philadelphia. "I paid no attention to my magnetic compass and only watched the country below me for available emergency landing fields," Smith wrote in a report to Praeger (Report of operation, 1920). Flying until he was able to receive equal signals on both the A and B coils, he looked down and saw the radio towers. He recommended the equipment be adopted in all Post Office aircraft, believing that had it been installed a few weeks earlier he would not have crashed in the Orange Mountains (Report of operation). Other pilots liked it. Claire Vance saw its value in getting the aircraft close to the field, but not practical for descent in instrument weather. Randolph Page thought it was a great tool for teaching new pilots the routes—in clear weather (Post Office survey forms, 1920).

There were problems with the equipment, and the problems would require substantial modifications. When the airplane was flown in or around inclement weather, the static and noise completely drowned out the navigation signal. Additionally, the headphones were extremely uncomfortable, prompting a comment from Harry Hucking: "Radio helmet hard on head [with] continuous use" (Post Office survey forms, 1920). Weather information in telegraphy code was also sent to aircraft in flight and proved to be useful to the pilots. A far more useful application, some pilots believed, would have been radiotelephony.

Other problems proved to be more serious. Aircraft ignition was a source of electrical noise and attempts to shield the receiver from its effects proved difficult. These obstacles led the NBS and Post Office to begin experimenting with an alternative system using a rotatable coil and a trailing wire. Although the experimental flights appeared promising, by

1921 a political turn of events made further development of the direction finder doubtful. Post Office support of radio navigation ended. Otto Praeger, Second Assistant Postmaster General, became more interested in the development of the transcontinental airway. Appropriations were soon cut with the election of Harding, who was not a supporter of Air Mail Service. The NBS continued to inform the Post Office of current radio research of interest to the Air Mail Service, but as far as Post Office projects were concerned the Bureau found it “impossible...to engage actively in the investigation of these problems on account of the lack of funds” (Bureau, 1922; Leary, 1995, pp. 99-100; Progress Report, January 15, 1921; Smith, 1931)

CONTINUED RESEARCH

As direction-finding experiments funded by the Post Office were ending, the Army continued to sponsor research. The following four joint Army-NBS projects (identified by NBS project codes) describe significant undertakings that began to shape the form of the aeronautical telecommunications system would take (Present program, 1922).

Project E-21a—Radio Direction Finding Research

The Army and NBS had been experimenting with direction finders and localized landing systems at McCook Field in Dayton, Ohio. Direction-finding work would continue, but at a slower pace. The NBS, with Army funding and collaboration, continued aeronautical telecommunications research.

Research in direction finding not only included its use as an airborne navigation aid, but as a terrestrially based direction finder as well. In other words, the Army not only wanted a direction finder in its aircraft for navigation purposes, but also had an interest in determining a bearing to an airplane in flight from a ground station. Two types of antenna systems for these airborne and terrestrially based methodologies were studied: a single-coil direction finder and crossed-coil equi-signal direction finder (Present program, 1922).

The single-coil direction finder was built on Kolster’s concept of a single rotatable coil. The null position was used to obtain a bearing to a transmission source, but in electrically noisy aircraft, the procedure proved difficult to use. The antenna, however, would find use as a terrestrially based direction finder.

The Robinson system, a form of equi-signal direction finding, employed two antennas but crossed at a ninety-degree angle—a smaller, main coil and a larger auxiliary coil. The placement of the antennas provided a minimum

signal when the airplane was homing to the beacon. This differed from the single coil, which produced a null. Having a minimum signal was preferable to the null and helped mitigate the effects of ignition noise (Keen, 1938).

Antenna tests conducted by the Army in the fall of 1921 produced remarkable results, Lt. Vaughn wrote to Whittemore at the NBS. Vaughn had concluded these preliminary tests had ruled out the use of the single coil method of direction finding for aircraft and added, "Our radio force was severely cut into during a recent 'economy' wave with the result that we are rather short-handed at present time" (Vaughn to Whittemore, 1921). The economy wave would affect the NBS as well and through 1925 the NBS would continue to follow, and when funding permitted, participate in the Army's direction finding experiments.

In a 1924 The Radio Laboratory report, experiments with direction finding for the Air Service reported that an equi-signal crossed coil system did in fact reduce the effect of electrical noise produced by engine ignition. The report included the work carried on with the single coil system and, when applied as a terrestrially based direction finder and a nearly vertical trailing wire antenna on the airplane, the system worked well (Memorandum for the director, 1924).

Collaboration with the Navy and Coast Guard produced improvement in antennas, operating frequencies and power requirements. By the summer of 1925 a high frequency direction finder had been developed with the cooperation of the Coast Guard. Such direction finders, operating at frequencies above 2000 kHz meant reliable direction determinations can be made. The Army Signal Corps had also experimented with high frequencies ranging from 3000 kHz to 7500 kHz. The Army reported that, "Such apparatus probably has a future in aircraft work because of the great distances covered by the high frequencies with small power and because of the smaller antenna needed" (Notes, 1925). The Navy also participated in direction finding research developing a cross coil equi-signal device that was made substantially automatic in action (Memorandum on conference, 1922; Memorandum for the director, 1924; Notes, 1925; Stratton, 1922).

Project E-24—Transmission of Directed Radio Waves From the Ground

In 1921, researchers began experimenting with a terrestrially based directive transmission navigational aid, one that produced a specific course and from which airways could be constructed. Navigating on a specific course, both to or from a station, eliminated the problem of drift found in homing, and could be used to define airways between airports or specific points on the ground. By March, Dellinger reported the results of an experiment based on crossing two coil antennas. Based on the earlier work

of Scheller and Bellini-Tosi, credited to NBS scientist Percival Lowell and developed by Francis Dunmore and Francis Engel of the Radio Laboratory, the concept was to transmit signals alternately on the same frequency from two crossed-coil aerials set at an angle of 135 degrees. The letter “R” was broadcast in Morse code on one antenna and the letter “L” on the other. The bisector of the 135-degree angle produced an area of equal signal strength and an aerial highway route (Progress Report, March 24, 1921). To remain on course, the pilot had to balance the intensity of the “R” and “L” in the headset. If the letter “L” became louder, the pilot would correct back to the right, and, likewise if “R” became louder the pilot would correct to the left (Snyder & Bragaw, 1986; Progress Report, March 24, 1921).

Tests were promising. Two, eight-foot, eight-turn, coils had been constructed and broadcasts were made at 300 kHz (1,000 meters). “The results when receiving at a distance of 3 miles were so encouraging as to warrant a more extensive investigation” (Snyder & Bragaw, 1986, p. 151; Progress Report, March 24, 1921). Results appeared in NBS’s *Scientific Papers of the Bureau of Standards* (Engel & Dunmore, 1924). The report explained aircraft using a directive beacon did not have to contend with the effects of wind drift as when navigating towards a nondirectional radio beacon. The Army was greatly interested and was sending its representative Lt. R.E. Vaughan to discuss the findings (Engel & Dunmore, 1924; McIntosh to Stratton, 1921).

The antenna system had been modeled after Scheller’s patented antenna system. Scheller’s course-setter employed an interlocking A and N signal to produce a course line. The resultant interlocking signal meant that not only would the Morse code representations of the two letters be heard equally on the course, but when heard equally, would form a continuous tone in the pilot’s headset. This is accomplished by transmitting the letter A on one antenna and N on the other. The Morse code for A is dot-dash while N is represented by a dash-dot. When the two are equal in intensity they produce continuous dashes, or an interlocked, signal (Keen, 1938; Report No. 6, 1925).

Further tests of cross-coil antennas were conducted on board the lighthouse tender *Maple* in the summer. The NBS placed a 2 kW quenched spark transmitter and two 150 feet by 50 feet antennas crossed at an angle of 143.5 degrees on the Bureau grounds. A receiving set was brought aboard the *Maple* and observations were made as the vessel traveled from Maryland Point to Colonial Beach Wharf. For this test the Morse code letters A and T were used (see Figures 8 and 9). As the ship made its way down the coast the researchers plotted a zone of equal intensity where small changes of intensity were difficult to discriminate. At thirty-one miles the zone had a width of one and one-fourth miles and the tests “established

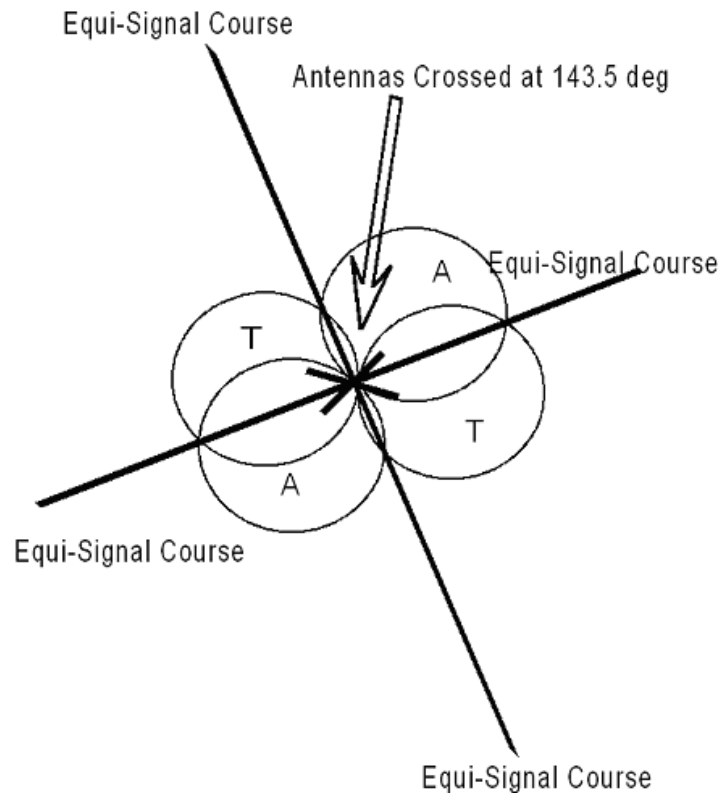


Figure 8. Crossed Coil Antenna System

without a doubt the existence of such a line or sector of equal signals” (Report on Equi-Signal, 1921).

Flight tests were made using a 250-foot trailing antenna and a 6-stage amplifier on a de Havilland aircraft. As long as the aircraft was on course the A and T broadcasts were equal, however, if the airplane turned ninety degrees to the course line, either the A or T would predominate. This had not been the experience on the Maple where there was an equi-signal zone. In flight the zone had been eliminated. The cause, the researchers believed, was the trailing antenna. The slipstream did not allow the antenna to remain perfectly vertical, a problem that would be mitigated by attaching a weight

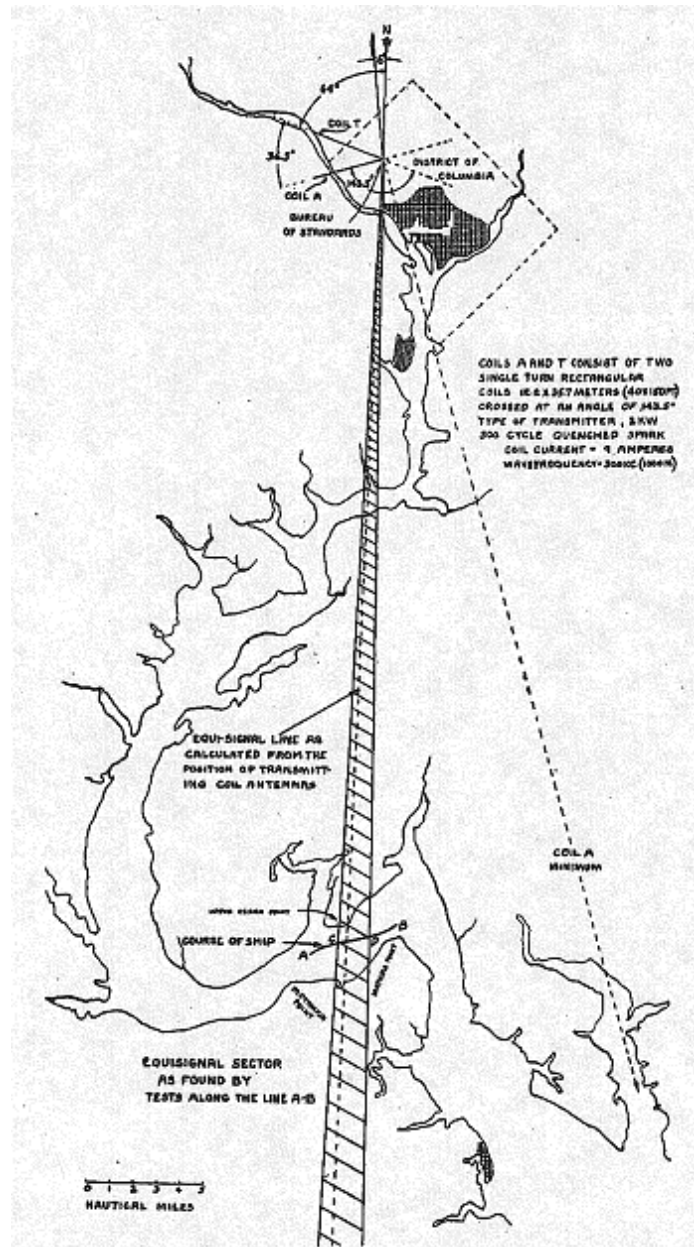


Figure 9. A Directive Type of Radio Beacon and Its Application to Navigation

From "A Directive Type of Radio Beacon and Its Application to Navigation, by F.H. Engel and F.W. Dunmore, 1924, Scientific Papers of the Bureau of Standards 19, p. 290.

to the end of the cable. The optimal solution lay in a shorter antenna, but its shorter length would degrade signal reception.

Some of the staff believed a cockpit indicator being investigated by the NBS offered a better solution. A visual system was superior to aural navigation. It eliminated the requirement for flight crews to constantly monitor the navigational signal. A visual indicator solved another potential problem—requiring pilots to switch between monitoring navigation signals to receive and transmit radio messages (Progress Report, June 16, 1921; Report of present status, 1921).

An extensive ground and flight test was completed in the fall of 1921. The transmitter, a 5 kW spark set, was placed in line with an automatic switching unit so the two antennas could be energized alternately. A DeHaviland 4B was modified to carry the inductively coupled tuner, VT-1 six-tube amplifier (with batteries) and the antenna reel and wire assembly. A total of four tests were flown and confirmed the signal changes had been due to the trailing wire antenna. Overall, the tests confirmed earlier findings. The system performed well at different altitudes and distances (Report on ground, 1921).

Not much progress was made during 1922. The NBS offered to help the Army modify or build a vacuum tube transmitter for use in navigation. “We shall be glad to assist in any way possible at the time of the Dayton tests in assembling the apparatus or in making adjustments” (Stratton, 1922) they wrote. Other work involved experiments in applying the visual course indicator to the aircraft receiver (Stratton, 1922).

By 1923 the NBS ceased further cooperative research due to a lack of funding. The Army, however, continued to study and perfect the directive navigational aid and experiment with vacuum tube transmitters. Another improvement, an experimental antenna and radiogoniometer, would add greater utility to the system. This new approach added flexibility by electronically bending the course. The original crossed-coil antenna patterned after Scheller’s concept produced courses, the bearings of which were dependant upon antenna placement. The ability to create an equi-signal course spaced at selectable angles was based on the Bellini-Tosi antenna system. The antennas could be crossed at ninety degrees and with a radiogoniometer or goniometer (see Figures 10 and 11) placed in the antenna circuit. This was an important breakthrough. If these NAVAIDS were to be used to define airways, the angle of the courses formed by their beams could not be limited to ninety degrees. Courses needed to be electronically bent to accommodate a route system (see Figure 12). The Army made one other improvement. They changed to the Morse code letters A and N thereby producing an aural interlocking course (Leary, 1995).

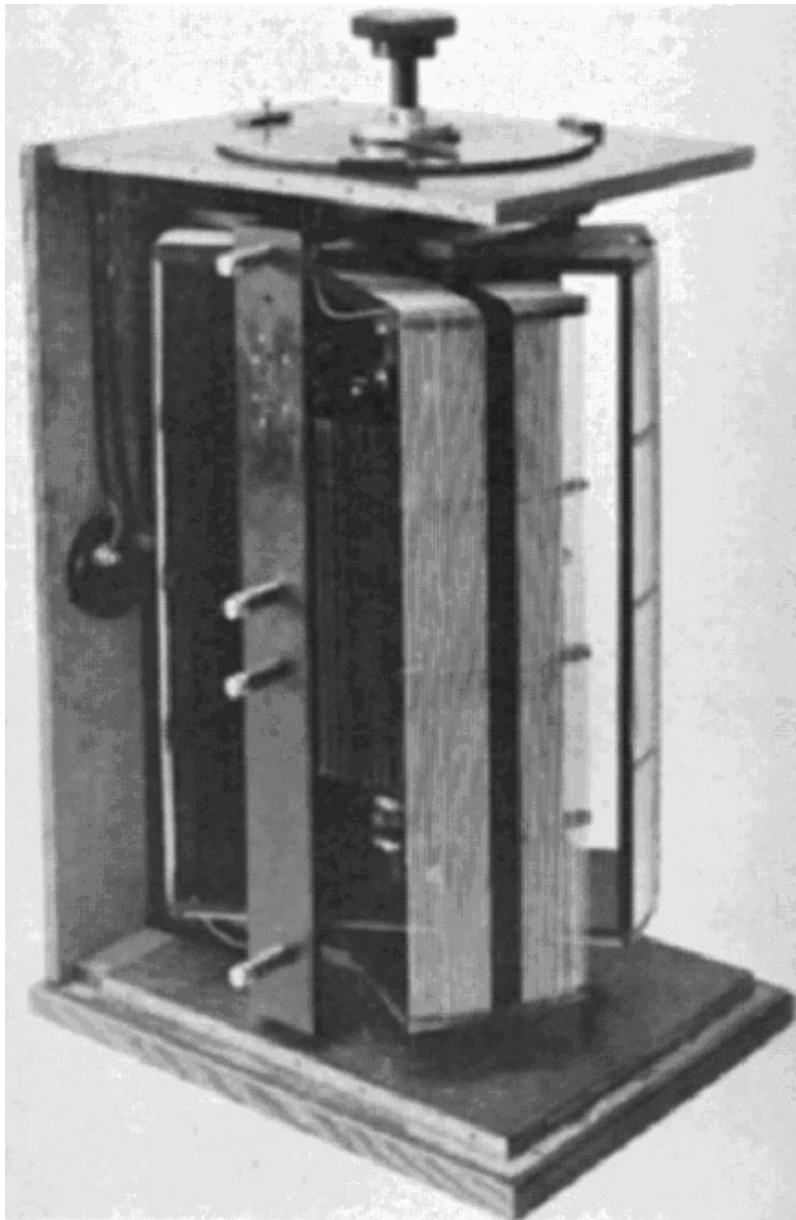


Figure 10. Goiniometer

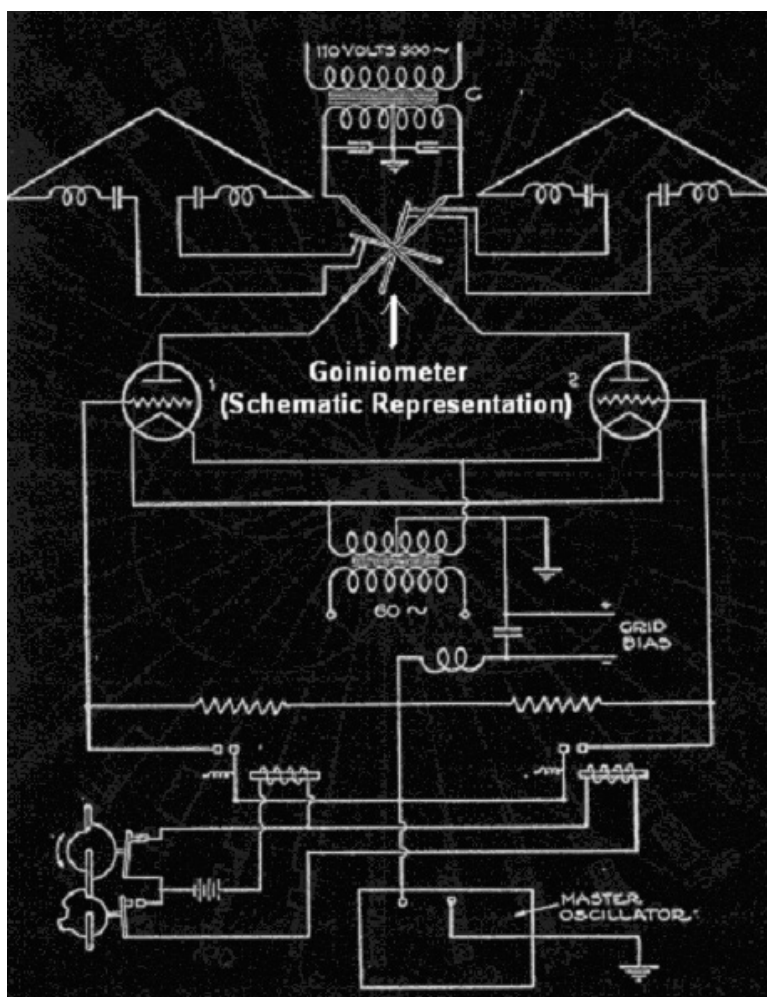


Figure 11. Schematic of Crossed-Coil Antennas with a Radiogoniometer

Project E-22—Visual Indicator for Radio Signals

The Army had expressed an interest in devising a method for the visual display of navigational signals in 1921. Several methods for accomplishing it were suggested including a vibration apparatus, a galvanometer, a light indicator and a recording device. Further research on visual indicators, however, would wait until after the passage of the Air Commerce Act in 1926 (Memorandum for the director, 1924; Notes, 1925).

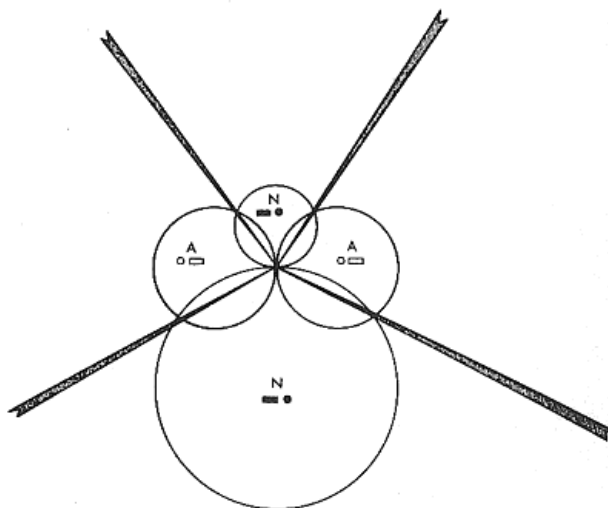


Figure 12. Goniometer Effects

Project E-25—General Aircraft Radio Problems

The Radio Laboratory had been conducting research on many aspects of radiotelephony since 1913. Its work included establishing radio transmission formulas, the study of radio wave phenomena, vacuum tube measurements, definitions and their use in amplifiers and radio communication. They developed standards for radio, studied the characteristics of antennas and undertook projects such as Kolster's fog signaling and direction finding devices. The NBS, in a confidential report to the Bureau of Efficiency, explained that its work in radio communications was not just investigatory or theoretical but that it had developed "radio devices from a laboratory stage to a plane where they are of practical service" (Radio communication, 1921).

Many applications developed from NBS research had military origins. The radio work for other administrative departments provided a healthy portion of their funding. Funding from these departments made up almost half the Bureau's income for fiscal years 1921 and 1922, with the War Department providing the lion's share. In fiscal year 1921 Congress had allocated \$30,000 for Bureau operations while the War Department had allotted \$25,000. While the Bureau consulted with other departments, its radiotelephony work was closely related to the needs of the Army and the

Signal Corps (Radio communication, 1921; Work of radio, 1920).

Work carried on by the Bureau for the Army's Air Service in 1921 comprised mostly of the study of vacuum tubes, measurements of insulators used in radio construction and testing procedures for radio receivers. Consultations with Underwriters Laboratories helped define aeronautical radiotelephony development issues and commercial aviation requirements for radio installation and range. Aircraft antenna size was a problem and the Bureau worked on problems that limited use on aircraft. Additional research was done with arc transmitters and radiotelephony (Work of radio, 1920).

The winter of 1921-1922 saw an important development. Lowell and Dunmore developed a receiver powered by alternating current (AC). Up until this point, receivers had to be powered by batteries because vacuum tube filaments and plates required direct current (DC). Lowell and Dunmore constructed a power supply that produced DC power from an AC source. They were able to use common 60 Hz AC power to operate a five-stage amplifier consisting of three radio frequency stages, two audio frequency stages and a tuning circuit. Another important experiment was transmitting using shorter wavelengths. By August 1922, a transmitter was ready for flight tests. The frequency was 30000 kHz (100 meters) and required a special antenna that had been developed by the Bureau. The test flight proved successful and the frequency "was found particularly adaptable to daylight transmission" (Snyder & Bragaw, 1986).

NBS scientist August Hund was assigned the task of employing quartz crystals for accurate frequency control in both transmission and receiving. "The Bureau has devoted considerable research during the past year to the use of piezo oscillators as frequency standards" reported the NBS in 1925 (Notes, 1925). Hund and his associate's efforts resulted in crystals that controlled frequency deviations and whistling caused by beat frequencies produced in heterodyne receivers (Snyder & Bragaw, 1986; Work of radio, 1920).

The Army sponsored the following projects, listed by the NBS title, until funding became unavailable in 1924. From that point until the creation of the Aeronautics Branch in 1926, the NBS did very little research for the Army Air Service or the Signal Corps (Snyder & Bragaw, 1986, Work, 1920).

THE POLITICS OF EARLY AERONAUTICAL TELECOMMUNICATIONS RESEARCH

The lack of political interest in communication and navigation research and the technologies required to support all weather flight, paralleled the

plight of aviation between the end of WWI and the Air Commerce Act of 1926 (Komons, 1978). The Army, Navy and Post Office were all vying for limited resources, as was the NBS. With the exception of the Post Office in 1925, very little research would be conducted until 1927. There had been no aviation champion of sufficient political clout who could overcome the parochial interests of the various administrative departments and see to it that a well-conceived plan supported by proper funding was put in place. Even though the NBS often functioned as a research coordinator among various administrative departments, it also was affected by the unpredictability of political budget process. The result was an uncoordinated and inconsistent development of aeronautical technologies. The on-again/off-again approach to research slowed development in the U.S. whereas in Europe, commercial aviation was alive and well supported by radio technologies. But European nations had taken a different approach. Countries such as England, Germany and France had directly supported not only the research, but also national airlines and requisite infrastructure as well. If the U.S. were to catch up to Europe, a political champion would have to emerge, a champion able to work within the political framework of national politics and one who would command the attention of the aviation industry as well. It would be necessary to bring all the government's research resources to bear on the challenges of communication and instrument flight. Aviation found its champion in Herbert Hoover. Hoover was not aviator nor was he involved in aircraft manufacturing, the airlines or military aviation. But, as Secretary of Commerce, he had a profound influence on the development of the aeronautical telecommunications system.

During his tenure as Secretary of Commerce, Hoover made two critical aeronautical telecommunications policy decisions (Johnson, 2001). The first answered the question of funding and who would pay for the communication and navigation infrastructure. The second answered the question of what form the would system take. What were the technologies to be developed? How should they be deployed? These two questions will be considered in Part Two.

Although Hoover had been educated as an engineer, he did not directly participate in the research and development of the system. Instead, his role was political, and his administrative and fiscal policies would ultimately ensure its utility and success. By the time Hoover left the Presidency in 1935, he had, as both Secretary of Commerce and President, overseen the growth of an aviation industry supported by an aeronautical telecommunications infrastructure that had become a model for the world.

ENDNOTES

1. Captain Lindbergh attributed the origin of his nickname "Lucky" to the New York papers covering his story. After landing in New York, where he made final preparations and waited for a break in the weather, his disdain for what he termed the "tabloid" press grew daily with each inaccuracy. See Lindbergh, 1953, pp. 150-162.

2. The term *aeronautical telecommunication* is not defined formally by the International Telecommunications Union (ITU), International Civil Aviation Organization (ICAO) or the Federal Aviation Administration (FAA). All three organizations have variations of the term when used in conjunction with other aspects of communication such as the Aeronautical Telecommunication Network (ATN) or descriptives such as "aeronautical telecommunication service." The definition used in this paper was derived from the *Oxford English Dictionary*, 2nd ed., s.v. "telecommunication," and the *American Heritage Dictionary of the English Language*, 3rd ed., s.v. "telecommunications."

3. The Fleming valve is named for its inventor, John Ambrose Fleming, an Englishman who had used it as a detector in receiving sets. He was granted a patent for his invention in 1904. See Snyder and Bragraw, 1986, p. 10.

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